



Using *Bininj/Mungguy* indicators to monitor the health of Country in Kakadu National Park

Final report

Cathy Robinson, Maria Lee, Ryan Barrowei, Bessie Coleman, Joe Markham, Billy Markham, Aaron Barrowei, Na-gangila Bangalang, Jonathan Nadji, Anita Nayinggul, Alfred Nayinggul, Sean Nadji, Simon Dempsey, Serena McCartney, Kenneth Mangiru, Jessie Alderson, Jennifer Macdonald, Justin Perry, Dennis Cooper, Feach Moyle, Kadeem May, Samantha Setterfield, Mat Gilfedder and Michael Douglas

© CSIRO, 2021



Using Bininj/Mungguy indicators to monitor the health of Country in Kakadu National Park is licensed by CSIRO for use under a Creative Commons Attribution 4.0 Australia licence. For licence conditions see creativecommons.org/licenses/by/4.0

This report should be cited as: Cathy Robinson, Maria Lee, Ryan Barrowei, Bessie Coleman, Joe Markham, Nangangila Bangalang, Johnathan Nadji, Anita Nayinggul, Alfred Nayinggul, Sean Nadji, Simon Dempsey, Serena McCartney, Kenneth Mangiru, Jessie Alderson, Jennifer Macdonald, Justin Perry, Dennis Cooper, Feach Moyle, Kadeem May, Samantha Setterfield, Mat Gilfedder & Michael Douglas. 2021 *Using Bininj/Mungguy indicators to monitor the health of Country in Kakadu National Park*. CSIRO, Brisbane.

Cover photographs

Front cover: Long-necked turtle is important bush tucker for *Bininj*, who hunt on the Nardab floodplain (photo: Mitchell Fong).

Back cover: Setting up cameras to help monitor the impact of cool burning at Jarrangbarnmi (photo: Michael Douglas).

This report is available for download from the Northern Australia Environmental Resources (NAER) Hub website at nespnorthern.edu.au

The Hub is supported through funding from the Australian Government's National Environmental Science Program (NESP). The NESP NAER Hub is hosted by Charles Darwin University.

ISBN: 978-1-925800-83-8

Printed by UniPrint

Contents

List of figures.....	ii
Acronyms & abbreviations	iii
Acknowledgements.....	iv
Executive summary.....	1
1. Introduction	3
1.1 Using <i>Bininj/Mungguy</i> indicators to assess and monitor sites in Kakadu	3
2. Methods	4
2.1 Indigenous-led co-designed research.....	4
3. <i>Bininj/Mungguy</i> indicators	7
3.1 The Healthy Country <i>Bininj/Mungguy</i> Indicator Dashboard	7
3.2 Using Indigenous-led artificial intelligence and digital technology	10
3.3 Country indicators	11
3.3.1 Protocols to use technology to help to see and hear Country.....	12
3.4 Culture and community indicators.....	13
3.5 Economic indicators – training and employment opportunities	14
3.6 Sharing Indigenous knowledge – between Elders, young people, and the community.....	16
3.7 Sharing science and Indigenous knowledge.....	18
4. <i>Bininj/Mungguy</i> indicators as decision triggers for adaptive joint management.....	20
References.....	22
Appendix 1: Summary of media, community newsletters and academic outputs	24
Appendix 2: Using knowledge to care for country: Indigenous-led evaluations of research to adaptively co-manage Kakadu National Park, Australia.....	26
Appendix 3: Understanding Indigenous values to prioritise on ground conservation efforts: lessons from the Nardab floodplain in Kakadu National Park.....	28
Appendix 4: Using Indigenous-designed artificial intelligence to support Indigenous-led adaptive management	29
Appendix 5: Indigenous-led responsible innovation: lessons from co-developed protocols to guide the use of drones to monitor a biocultural landscape in Kakadu National Park, Australia.....	30

List of figures

Figure 1. Bininj/Mungguy Research Steering Committee members, local Traditional Owners and district rangers meet regularly to guide and monitor the Kakadu National Environmental Science Program (NESP) project at each site.	5
Figure 2. Understanding Bininj/Mungguy values for landscapes and sites in Kakadu help explain locally driven cross-cultural conservation priorities and activities.	6
Figure 3. Healthy Country Bininj/Mungguy Indicator Dashboard allows each site to be assessed in an Indigenous-led and holistic way and for Bininj/Mungguy, park rangers and scientists to use data to have a dialogue about the health of Country at selected sites.	8
Figure 4. Using Bininj/Mungguy healthy Country indicators to adaptively assess Country.	9
Figure 5. Details of the design and application of our Indigenous-led Healthy Country AI model for environmental decision-making.	10
Figure 6. The Healthy Country AI model was designed to empower Indigenous land managers to rapidly survey large areas and interpret drone-collected footage to show important changes to the ecosystem following on-ground management interventions. Source: Robinson et al. (in review; for details see Appendix 4).	11
Figure 7. Elders describe the importance of working together to assess and monitor the health of Kakadu for Country and community (for details see Appendix 1).	13
Figure 8. Indigenous co-researcher involvement was key to the success of this Kakadu National Environmental Science Program (NESP) project.	14
Figure 9. Tracking who participated in Kakadu National Environmental Science Program (NESP) co-research activities and what skills they acquired.	15
Figure 10. Tracking Bininj/Mungguy knowledge-sharing activities supported by Kakadu National Environmental Science Program (NESP) activities and project.	17
Figure 11. Tracking science and Bininj/Mungguy knowledge sharing, and co-research activities supported by Kakadu National Environmental Science Program (NESP) project.	19

Acronyms & abbreviations

AIartificial intelligence

I-AIIndigenous-led artificial intelligence

M&Emonitoring and evaluation

NESPNational Environmental Science Program

RSCResearch Steering Committee

Acknowledgements

We all feel good about ourselves when we are working together on this project because we are motivated by being together on Country. We acknowledge the generosity of Traditional Owners across Kakadu in welcoming the research team and sharing their stories with us. We would like to thank the Kakadu and Njanjma Rangers and staff who worked so hard on this project. We would also like to thank our Microsoft collaborators who supported the Healthy Country AI (artificial intelligence) component of the work. Finally, we acknowledge the other collaborative research that we built on to support this research. We have all worked hard to build this relationship and we want to keep working together to make sure Country is healthy in Kakadu.

Executive summary

This is an Indigenous-led action-research project focused on the development and trial application of *Bininj/Munggyu* healthy Country indicators in Kakadu National Park (Kakadu). To achieve this goal, we worked together with the Traditional Owners responsible for pilot areas to undertake targeted field studies to identify Indigenous values and the indicators used to track the health of Country before and after agreed on-ground management activities.

Under the direction of a *Bininj/Munggyu* Steering Committee, five indicators were identified to assess sites and guide the adaptive management of important landscapes within this jointly managed and Ramsar-listed World Heritage Area. These included:

- **Country** – health and abundance of bush tucker species
- **culture and community** – community access, engagement, and connection to Country
- **economic** – training and employment opportunities to care for Country
- **sharing Indigenous knowledge** – between elders and young people on Country together
- **sharing science and Indigenous knowledge** – research collaboration, activities and impact.

Together with *Bininj/Munggyu* Traditional Owners and rangers, we have trialled an approach for monitoring and reporting on healthy Country indicators before and after agreed on-ground actions. In this report, we outline how these indicators were used to monitor and evaluate weed management actions at Nardab and landscape burning activities at Jarrangbarnmi.

The results of this project have been translated into an interactive **Healthy Country *Bininj/Munggyu* Indicator Dashboard¹**, which was co-designed to allow *Bininj/Munggyu*, Kakadu rangers and staff, and scientists to share data collected to assess sites before and after agreed activities using the five indicators outlined above. The interactive digital platform and reporting tool and a practical video guide have been shared with *Bininj/Munggyu* and Kakadu rangers and staff and data visualisation snapshots for each indicator are presented in this report. The platform shows how *Bininj/Munggyu* indicators have been used to assess agreed management activities on the Nardab floodplain and in the lowland woodlands near Jarrangbarnmi. The results of this work provide a practical approach and insights into how *Bininj/Munggyu* healthy Country indicators could be integrated into Kakadu's monitoring and performance reporting programs. The indicators and approach can easily be adapted for cross-cultural monitoring and performance reporting for other landscapes and threatening processes in Kakadu, as well as for other jointly managed parks across Australia.

Through this project, we co-designed an approach to use technology responsibly to help monitor important sites through the Indigenous-led Healthy Country Artificial Intelligence (AI) model. The Healthy Country AI approach uses science and Indigenous knowledge to regularly survey large areas that are difficult to access by converting large volumes of data

1

<https://app.powerbi.com/view?r=eyJrIjoiaWMyNjA5N2MtNWRINS00ZWZWM0LWEwMDktMWQxNGNmNmY1ZDg4liwidCI6IjYwMjI4YjdjLTM5MzQtNDMxMC1hMjdkLTI1MzZkZDFiZGY5ZCJ9&pageName=ReportSectiond973d3ab06cb6deed0c0>

into metrics to demonstrate how the key features of Country health (e.g. magpie geese numbers) are changing following agreed management interventions. The model code is freely available on GitHub (<https://github.com/microsoft/HealthyCountryAI>). We were proud to be announced as a Eureka Prize finalist (https://www.nespnorthern.edu.au/2020/09/29/eureka_finalist) for our innovative work.

This report, the Healthy Country Bininj/Mungguy Indicator Dashboard and the Healthy Country AI model are part of a series of outputs and celebrations that have been delivered from this work. The outputs are summarised in this report and include a video (<https://vimeo.com/430230796>) where Traditional Owners, Kakadu rangers and research scientists explain the impact of this collaborative effort on the Nardab floodplain.

Over 30 *Bininj/Mungguy* co-researchers have been employed and engaged in this research project. As Maria Lee, who was the chair of the Board of Management and is a Traditional Owner for Jarrangbarnmi, said when interviewing 2 young family members, Jermaine Douglas and Elijah Gayoso, being on Country with this project 'refreshes your mind'. Jermaine agreed, with his trips to Jarrangbarnmi to learn from senior Traditional Owners making him '*feel welcome. It's alright. Stress-free. Enjoy Country, eating bush tucker and stuff*'. We have made sure we encouraged and supported young people to join us and use the technologies developed to assess and monitor these sites. As Elijah highlighted, of equal importance has been the opportunity to learn about new technologies and be on Country with Traditional Owners:

I like learning about how the technology works. So, when you ... come out here with the ranger and you take out all this thing and then you already know how it works because Balanda showed us how to work it. ... It's good to come out here, like in person, because you feel connected to the land, so you don't want to just listen from a laptop or something. Just think 'oh there the birds'. It's gonna make you think 'oh we should go back out there' and then you're gonna come back out here and then really see for yourself how it's like. You'll probably come back out here and start crying because you miss everything.

Together, we have introduced a monitoring approach that *Bininj/Mungguy* can use all the time, to see the results of what we are doing together, and this makes us all excited to learn and engage in this Indigenous-led research. We want to share what we have done here in Kakadu to show other park managers, rangers and Traditional Owners good ways to work together.

1. Introduction

1.1 Using *Bininj/Mungguy* indicators to assess and monitor sites in Kakadu

The science and practice of multiple evidence-based approaches to inform environmental decision-making has matured in recent decades (Robinson et al. 2016; Sterling et al. 2017). Monitoring and evaluation (M&E) frameworks and methodologies developed to provide this evidence often only use western science and approaches which continue to be challenged by poor access to scientific data, and difficulty in integrating M&E insights into improved management practices (Hockings et al. 2006). Most M&E frameworks are also limited in their ability to accommodate Indigenous knowledge and world-views of human-environment relationships, Indigenous healthy Country assessments, the role culture plays in enhancing the beneficial relationships between nature and people, the type of management processes and practices that are valued, or the way outcomes of management decision-making and activities are assessed (Robinson and Wallington 2012; Cámara-Leret et al. 2019).

Those Indigenous M&E frameworks that have been developed are typically affected by some limitations. Often, Indigenous biocultural indicators and M&E frameworks are developed that only focus on ecosystem attributes rather than offering an Indigenous-led and holistic approach to monitor and evaluate human-environment relationships or recognising the links between cultural and biological heritage (e.g. Austin et al. 2017; McKemey et al. 2020). Indicators that bring together human and environmental interrelationships have been proposed, yet how these indicators might explicitly trigger management or policy decisions remains theoretical (Caillon et al. 2017). This is surprising given the importance of Indigenous lands for biodiversity conservation, the growing and global recognition of Indigenous rights to and relationships with the environment, and the role that Indigenous culture and people play in enhancing the beneficial contributions between nature and people (Diaz et al. 2018).

This Kakadu National Environmental Science Program (NESP) research responded to this gap by identifying indicators developed by *Bininj/Mungguy* Traditional Owners that were used to assess sites before and after agreed joint management activities in this World Heritage and Ramsar-listed area. This work required us to extend the science and application of landscape health indicators that just focused on ecological attributes in a given area to consider the holistic ecological, cultural, knowledge and human dimensions of healthy Country from Indigenous worldviews.

2. Methods

2.1 Indigenous-led co-designed research

The principles of Indigenous-led co-designed research are often outlined but insights to guide the practice of this approach are rarely explained. The design and application of Indigenous-led co-designed research in Kakadu National Park required considerable attention, rigour and resources to ensure *Bininj/Mungguy* could steer, monitor and remain engaged in the research and its impact. In large regions such as Kakadu, it is important to nest strategic regional-level governance arrangements with local clan-based efforts to guide research goals and impact (Austin et al. 2019).

Our Kakadu National Environmental Science Program research project was governed by a *Bininj/Mungguy* Research Steering Committee (RSC) made up of Elder representatives of all the clans in the park. Relevant clan representatives on the RSC worked with Elders at each of the chosen sites and directed the research team's on-ground research activities (Figure 1). Priority areas and issues were selected by the RSC to focus research team efforts and activities – the floodplain site at Nardab/East Alligator in the north of the park, where research focused on weed control; and the stone Country site at Jarrangbarnmi/Koolpin Gorge in the south of the park, where research focused on fine-scale cultural fire management. Anlarr/Nourlangie camp was also chosen to focus on feral pig, weed and fire management issues. This work did not progress significantly because the site was damaged and deemed too dangerous to visit following a fire in 2019. The progress of on-ground efforts was also impacted by travel and social distancing restrictions caused by the COVID-19 pandemic.



Figure 1. Bininj/Munggyu Research Steering Committee members, local Traditional Owners and district rangers meet regularly to guide and monitor the Kakadu National Environmental Science Program (NESP) project at each site.

Communicating the results of our research so that it could be used and understood by all our collaborators was a priority. A summary of community updates, videos and media interest in this work is outlined in Appendix 1. Details of the context and approach underpinning the Kakadu NESP project are summarised in research papers, that have been prepared as part of this work, submitted to journals and are either under review or accepted for publication (see Appendix 2, Appendix 3, Appendix 4, Appendix 5). This includes our paper that outlines how we designed, implemented, and evaluated Indigenous-led co-designed research in Kakadu (Appendix 2). A core finding from this effort was that Indigenous evaluations of research emphasise the qualities of knowledge sharing, co-creation and translation that Indigenous people value and highlight the benefits research practice and impact needs to deliver for it to be judged as useful to Indigenous people.

Workshops were held with Traditional Owners and rangers at Nardab/East Alligator floodplain and Jarrangbarnmi/Koolpin Gorge to identify indicators that could be used to assess the health of Country and agree on the monitoring approach to trial (Figure 2). At each site, we explored the specific combinations of Indigenous and conservation values in terms of their capacity to support suitable habitat for important bush tucker species, support for cultural, community and knowledge-sharing values and activities, and the ecosystem services each site provides to visiting tourists. The mix of Indigenous values then informed decisions on where and why to prioritise on-ground management and other Indigenous stewardship activities.



Figure 2. Understanding Bininj/Mungguy values for landscapes and sites in Kakadu help explain locally driven cross-cultural conservation priorities and activities.

Details of how we considered *Bininj* values for the Nardab floodplain and showed why and how the diversity of these values can guide locally driven cross-cultural conservation priorities and activities are outlined in Appendix 3. The diversity of meanings and metrics around Indigenous values for the Nardab floodplain echo the complexity and diversity of Indigenous values in other parts of Australia and more broadly. Indigenous values need careful discussion and understanding to guide Indigenous-supported environmental management and restoration priorities and activities.

At Nardab, three sites were selected to monitor magpie geese and turtle numbers before and after para grass was sprayed and controlled. At Jarrangbarnmi, Traditional Owners chose wattle trees and its habitat near the camping site, escarpment, and creek to monitor the impacts of before and after on-ground Indigenous-led landscape burning efforts.

3. *Bininj/Mungguy* indicators

Under the direction of the Kakadu National Environmental Science Program *Bininj/Mungguy* Research Steering Committee and Traditional Owners for Nardab and Jarrangbarnmi, five indicators were identified to assess sites and guide the adaptive management of important landscapes within this jointly managed, Ramsar-listed World Heritage Area. These included:

- **Country** – health and abundance of bush tucker species
- **culture and community** – community access, engagement, and cultural connection to Country
- **economic** – training and employment opportunities to care for Country
- **sharing Indigenous knowledge** – between elders and young people on Country together
- **sharing science and Indigenous knowledge** – research collaboration, activities, and impact.

3.1 The Healthy Country *Bininj/Mungguy* Indicator Dashboard

Together, we developed a data-sharing dashboard that could be used by *Bininj/Mungguy*, scientists and park rangers and staff to use *Bininj/Mungguy* indicators to assess selected sites before and after agreed management interventions. Workshops were held with *Bininj/Mungguy* Traditional Owners and park rangers to refine the dashboard so that it could be used as part of day-to-day activities and align with indicators used in Kakadu's Performance and Reporting Plan. Key to this effort was to ensure *Bininj/Mungguy* assessments at each site could be viewed in a holistic way, that the dashboard could facilitate a dialogue with the data provided by *Bininj/Mungguy*, park rangers and scientists, and that site assessments could easily be updated using Indigenous data governance and consent protocols (Figure 3).



Kakadu Project Overview

What is this study about?

Using responsible AI and Indigenous knowledge to solve complex environmental management problems and care for important values across Kakadu National Park.

What values are we protecting?

This study aims to protect a range of Healthy Country Indicators, summarised below:

Icon	Indicator	Description
	Country	Culturally and ecologically significant species and habitats
	Community	Access to country, stories and memories
	Economic	Jobs, training and on-country enterprises
	Sharing Indigenous Knowledge	Sharing Indigenous knowledge between Traditional Owners and young people
	Sharing science and Indigenous Knowledge	Sharing knowledge between Bininj/Munggy, scientists and Park Rangers and Staff

Select a monitoring site and click on the image to learn more

Jarrangbarnmi
Nardab

Reset Map

This project is a collaboration led by Traditional Owners through the Bininj/Munggy Research Steering Committee.
Photo Credits: Michael Douglas, Cathy Robinson, Michael Fong



Figure 3. Healthy Country Bininj/Munggy Indicator Dashboard allows each site to be assessed in an Indigenous-led and holistic way and for Bininj/Munggy, park rangers and scientists to use data to have a dialogue about the health of Country at selected sites.

During each trip, we reflected on each *Bininj/Mungguy* indicator with a survey and scoring system using a Likert scale from 1 to 5, where 1 = unhealthy and 5 = healthy (Figure 4). Health assessments were discussed as a group and key actions were identified for follow up by the Kakadu NESP team or park rangers.



Figure 4. Using *Bininj/Mungguy* healthy Country indicators to adaptively assess Country.

3.2 Using Indigenous-led artificial intelligence and digital technology

Surveying vast areas in remote parts of Australia can be difficult and there is a need to turn what can seem an intractable environmental management problem into an achievable solution. When thinking through this challenge, we identified the need to develop an approach that directly empowers local communities to use the capability of digital technology to respond to complex environmental management issues in a coordinated, long-term and measurable way.

In Kakadu, we developed Indigenous-led and ethical ways to design and apply innovative technologies to solve complex environmental management problems facing each area. Details of the design and application of our Indigenous-led artificial intelligence (I-AI) Healthy Country model can be found in Appendix 4 and each step is summarised in Figure 5.

Important aspects of this Indigenous-led process were to ensure the co-design and use of digital technologies that enable data collection and analytical efforts – such as the Healthy Country AI model – are governed by Traditional Owners, reflect the priority areas of concern for Traditional Owners and rangers, respond to the seasonal aspects of Indigenous people’s stewardship of their estates, and support on-ground adaptive co-management efforts. The Healthy Country AI solution has also been constructed with several layers of privacy, as some of the sites where the drones collect data are sacred to Traditional Owners and imagery and data from those sites need to be properly protected.



Figure 5. Details of the design and application of our Indigenous-led Healthy Country AI model for environmental decision-making.

3.3 Country indicators

At Nardab, we co-developed and trialled an Indigenous-led Healthy Country AI model to enable us to monitor Country indicators by rapidly surveying large areas and interpret drone-collected footage to show important changes to the ecosystem following on-ground management interventions. The Healthy Country AI model converts large volumes of data (thousands of high-resolution photos) into metrics – in this case, magpie goose numbers and spread of para grass – to demonstrate how *Bininj*-identified country indicators are changing following management interventions. A snapshot of our trial at Nardab is outlined in Figure 6. The dashboard shows how technologically collected data can be presented and used alongside *Bininj/Mungguy* assessments of this area.

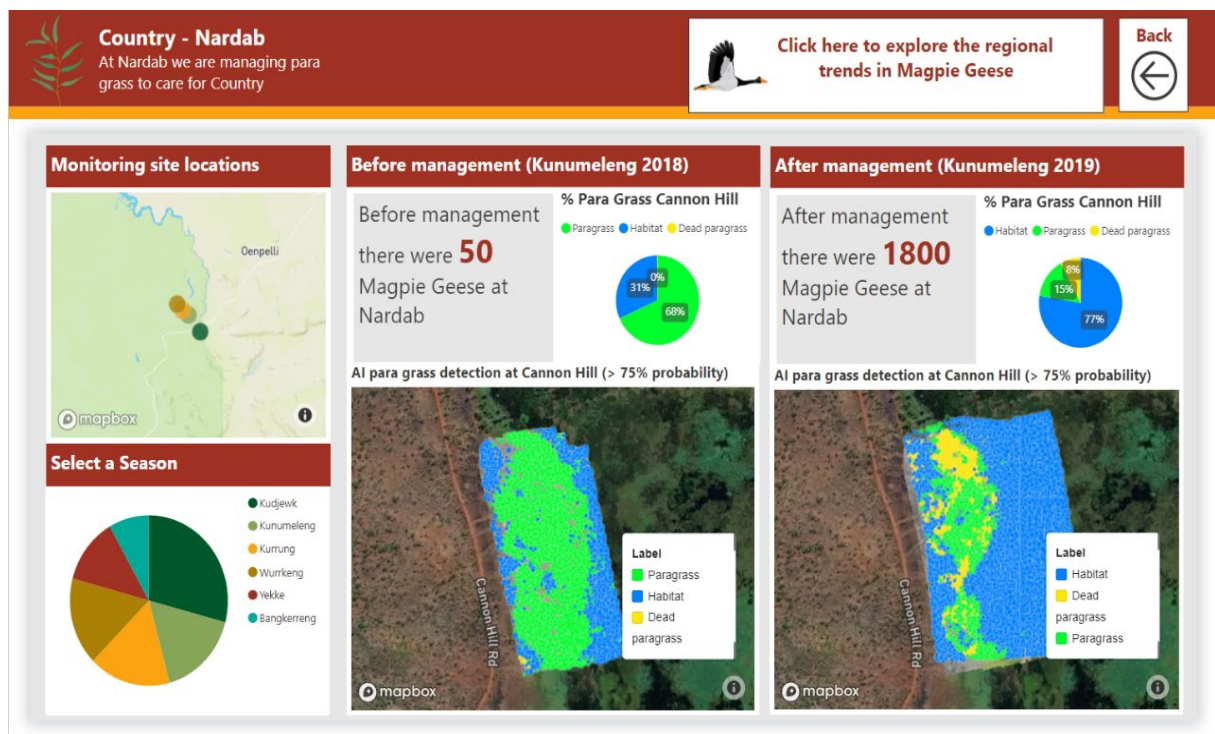


Figure 6. The Healthy Country AI model was designed to empower Indigenous land managers to rapidly survey large areas and interpret drone-collected footage to show important changes to the ecosystem following on-ground management interventions. Source: Robinson et al. (in review; for details see Appendix 4).

3.3.1 Protocols to use technology to help to see and hear Country

At Nardab and Jarrangbarnmi, we agreed to trial motion-sensor cameras and sound recorders, for ‘seeing’ and ‘hearing’ Country when people were not there; and drones, for collecting aerial photos to monitor changes to Country over time. Traditional Owners at both sites raised their concerns regarding the drone, including that the user might ‘see’ restricted sacred sites, including gendered sites, or that sensitive information might be recorded in an open-access database; or that Traditional Owners might be removed from decision-making processes on Country. As highlighted in our review of an on-Country workshop at Jarrangbarnmi:

It’s alright that you bring that technology, but you need to make sure you bring TOs [Traditional Owners] with you when you’re setting it up so they’re still on Country, learning and listening to Country.

– Wurrkbarbar Traditional Owner, Jarrangbarnmi, 25/06/2019

We co-designed protocols to ensure drones and the data collected responded to privacy, data ownership and protection, and ethical risks identified from drone use and surveillance (for details see Appendix 5). These protocols include the need to:

1. empower Indigenous governance for Country to decide when technology should be used and how it can benefit *Bininj/Mungguy*
2. respect kin-Country relationships to guide where, when and what technology can help Traditional Owners and rangers to see and hear, when they are on Country and when they are not
3. enable training opportunities so Traditional Owners and rangers can use this technology, especially their young people.

These protocols provide a way for Indigenous people to guide and authorise the introduction of new technologies that are used to produce new knowledge needed to adaptively co-manage Indigenous people’s lands.

3.4 Culture and community indicators

Ensuring *Bininj/Mungguy* can access and connect to Country was identified as an important cultural and community outcome of the successful adaptive management of threats to Country. Having a healthy and living culture means supporting language, knowledge, history, kinship and law, which are all passed through stories, song and ceremony from Elders to young people on Country. To track the success of this indicator, *Bininj/Mungguy* suggested using voice recordings of Traditional Owners which were made on Country and had Traditional Owners assessing the health of *Bininj/Mungguy* access, engagement and connection to Country, including to hunting and ceremonial sites (Figure 7).

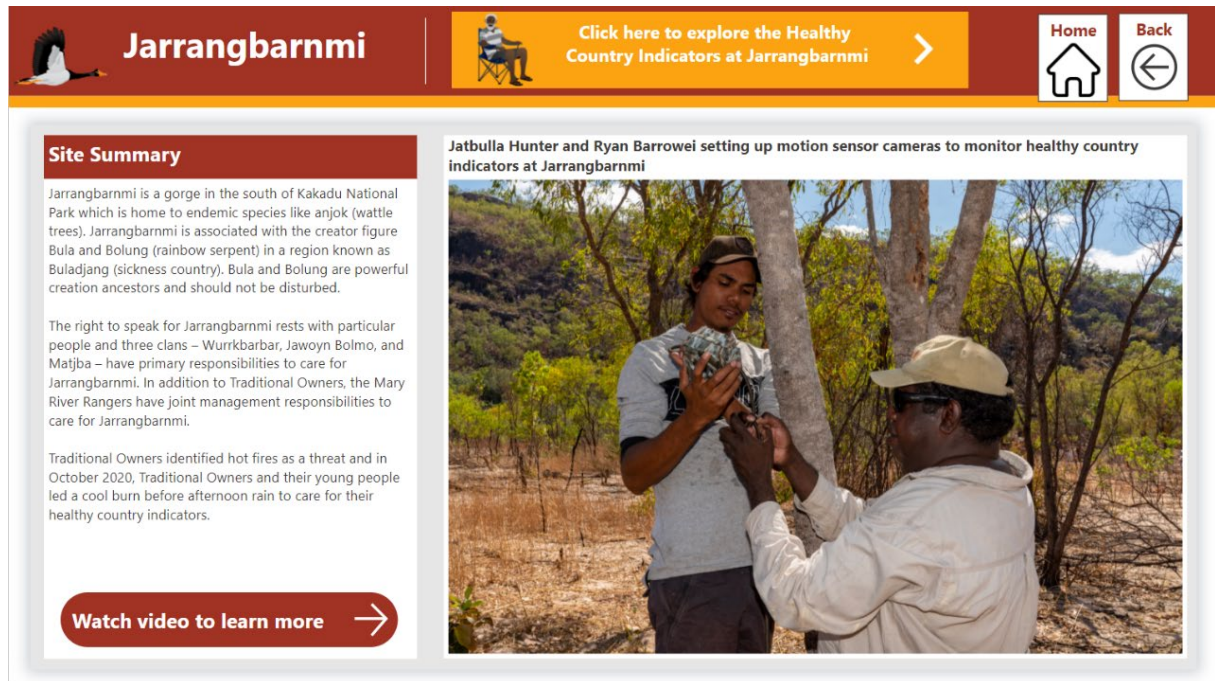
Empowering local *Bininj/Mungguy* people and communities to drive and be engaged in the Kakadu NESP project was a critical aspect of this project. We worked hard to ensure research directions, outputs and impact were clearly communicated by and for *Bininj/Mungguy* people. Appendix 1 summarises community summary sheets and videos created through this project.

The screenshot displays a mobile application interface with a dark red header. On the left, a small icon of a person is next to the text 'Community' and 'Listen to Traditional Owners monitoring the health of community indicators'. On the right, there are 'Home' and 'Back' navigation buttons. The main content area is split into two columns. The left column features a video player with a thumbnail of Bessie Coleman, a Traditional Owner, holding a branch. Below the thumbnail is a play button and a progress bar showing '0:00 / 1:18'. The right column features a video player titled 'Watching and listening to Country' showing a timelapse of a forest. Below the video is a caption: 'This video was made using a timelapse camera and a sound recorder, which Traditional Owners and researchers put on country from Malapparr (August) 2019 to Jungalk (October) 2020. The pictures and the sound let us see and hear country when we are not there.'

Figure 7. Elders describe the importance of working together to assess and monitor the health of Kakadu for Country and community (for details see Appendix 1).

3.5 Economic indicators – training and employment opportunities

On-ground research and training opportunities were identified as an important indicator to monitor because of the priority placed on possible employment opportunities for *Bininj/Mungguy*, including in research projects or to apply to other industries doing environmental and cultural monitoring assessment and management. Considerable effort was made to enable Indigenous co-researchers who were employed through the project and engaged in a range of on-ground research training opportunities (Figure 8).



The screenshot shows a website interface for 'Jarrangbarntmi'. The header includes a logo of a bird, the title 'Jarrangbarntmi', a navigation link 'Click here to explore the Healthy Country Indicators at Jarrangbarntmi', and 'Home' and 'Back' buttons. The main content area is divided into two sections. On the left, under the heading 'Site Summary', there is text describing the location and cultural significance of Jarrangbarntmi, including its association with the creator figure Bula and Bolung, and the responsibilities of Traditional Owners and the Mary River Rangers. A 'Watch video to learn more' button is located at the bottom of this section. On the right, there is a photo titled 'Jatbulla Hunter and Ryan Barrowei setting up motion sensor cameras to monitor healthy country indicators at Jarrangbarntmi'. The photo shows two individuals in a natural setting, one holding a camera and the other assisting with its setup.

Figure 8. Indigenous co-researcher involvement was key to the success of this Kakadu National Environmental Science Program (NESP) project.

We tracked who participated in Kakadu NESP co-research activities and accessed training through our on-ground fieldwork. We were proud to see the steady increase in ongoing engagement in the project. A summary of how this information could be used to guide future cross-cultural monitoring and reporting efforts is summarised in Figure 9.

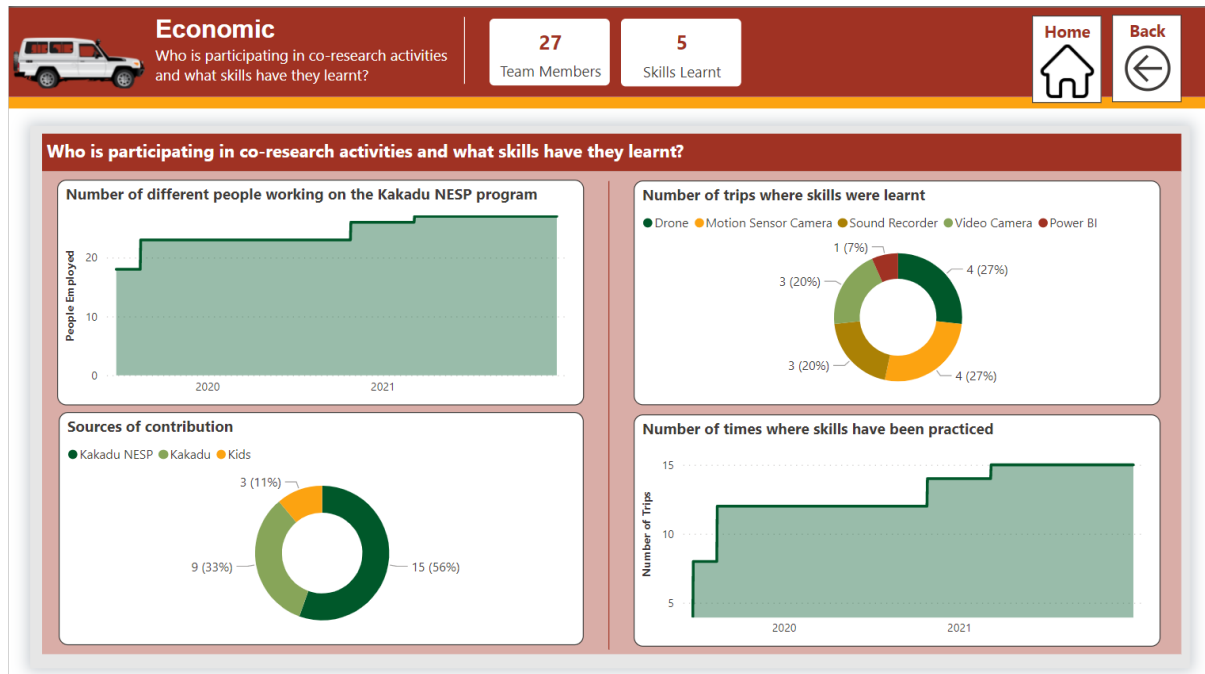


Figure 9. Tracking who participated in Kakadu National Environmental Science Program (NESP) co-research activities and what skills they acquired.

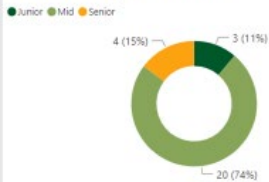
3.6 Sharing Indigenous knowledge – between Elders, young people, and the community

Efforts to ensure knowledge could be shared between *Bininj/Mungguy* Elders and young people was identified as a critical aspect of assessing sites and monitoring the impacts of agreed on-ground activities. Young people were encouraged to be part of our 1–5 healthy site assessment and used videos to interview their Elders about important species and actions needed to care for each area (see Appendix 2 for details). For the indicator on ‘sharing Indigenous knowledge’ we tracked the number and type of trips to Country, because for Country to be healthy, people need to spend time caring for it and using the knowledge and language that has been passed on from Elders to young people for many generations. This information and approach could be used to ensure *Bininj/Mungguy* cultural knowledge and practices are being enabled in adaptive management activities, as well as providing part of the evidence base to track Looking after Country indicators, outlined in the Kakadu National Park Performance Monitoring Plan. An example of how this is presented in our Healthy Country dashboard is shown in Figure 10.



How are we sharing Indigenous Knowledge?

Breakdown of experience levels



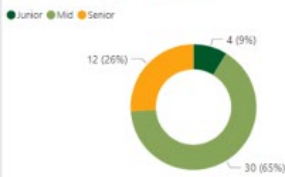
Number of trips to Country for different activities

Activity	Number of Day Trips	Number of Overnight Trips
Cultural fire	1	
Fishing	2	2
Knowledge sharing	2	2
Monitoring	2	1
Planning	1	1



How are we sharing Indigenous Knowledge?

Breakdown of experience levels



Number of trips to Country for different activities

Activity	Number of Day Trips	Number of Overnight Trips
Knowledge sharing	8	
Long-necked turtle hunting	1	
Monitoring	20	
Planning	7	
Weed management	3	



Figure 10. Tracking Bininj/Munggy knowledge-sharing activities supported by Kakadu National Environmental Science Program (NESP) activities and project.

3.7 Sharing science and Indigenous knowledge

This indicator aligns with the research and monitoring performance indicator outlined in the Kakadu National Park Performance Monitoring Plan. We built Indigenous-led evaluation processes to assess our collaborative knowledge work and research practices into the entire life cycle of the Kakadu NESP project using a Likert scale from 1 to 5, where 1 = unhealthy and 5 = healthy. We paid particular attention to creating a safe space for qualitative feedback, with details of this process found in Appendix 2. At the request of our *Bininj/Mungguy* Research Steering Committee, we tracked this engagement and used this information to adapt assessment and monitoring activities trialled in this project and to encourage *Bininj/Mungguy* people to be involved (Figure 11). The RSC and co-researchers were empowered to monitor and evaluate the Kakadu NESP team's efforts to:

1. **Negotiate the context of the research.** This included ensuring Traditional Owners were leading decisions about what to research, where to do it, and who needed to be involved.
2. **Enable adaptive and collaborative decision-making at multiple decision-making scales.** This is important in places like Kakadu where Indigenous peoples' knowledge systems and decision-making practices are Country-based (local). It also enables research to be used in contexts where co-management is governed and nested between multiple scales, including local, district, and the region (whole-of-park). Decision-making mechanisms therefore needed to support monitoring and management that is locally grounded and validated, and applicable at the district scale and across the park.
3. **Undertake Indigenous-led research activities.** This focused on the usefulness of the research and usability of knowledge generated from the project for *Bininj/Mungguy* Traditional Owner efforts to jointly manage their estates.

Care was taken to ensure the evaluation process was culturally safe so that Indigenous partners could lead, understand and learn about research activities and impact and the Kakadu NESP team could learn and respond to Indigenous perspectives and aspirations. The Research Steering Committee decided that the research evaluation would occur after the research team had monitored each adaptive management effort at each of the case study sites, after local-district workshops and after regional-scale RSC meetings. Based on feedback from evaluations of the Indigenous-led research activities at each site, the research team would adapt project activities, outcomes, and methods as necessary.

The most positive aspect of this effort was that issues that arose during the life of this Kakadu NESP project could be regularly monitored and agreed actions rapidly negotiated. This enabled us to find ways to work well together and to trial innovative ways of monitoring sites in Kakadu, with our strong collaborative and innovative work recognised nationally (e.g. as a [Eureka Prize finalist](#)). As Maria Lee, previous Chair of Kakadu Board of Management, eloquently put it:

We've worked hard to build this relationship and we want to keep working with you. This NESP team brings Bininj to life here, they feel good about themselves because you motivate them. You did a good job; our young people are happy, and I want to see it keep going so we can keep motivating our young people.

As discussed in detail in Appendix 2, this unique approach to evaluate Indigenous-led collaborative knowledge work seeks to negotiate, create, collect and analyse evidence to guide adaptive management decisions. Evaluations of this NESP project in Kakadu

recognised the collaborative cross-cultural conditions that enable knowing sharing, testing and translation, and the need to respect the agency of Indigenous people to assess the quality of working knowledge used to guide research on their Country. This evaluative effort resulted in strengthened knowledge-sharing practices and more effective collaboration, enabling the project to achieve its desired impacts (see Figure 11). This demonstrates the value of empowering Indigenous perspectives on how knowledge can and should be used to guide adaptive decision-making and learning.

The need to ensure research is useful and useable is of global academic and practical concern and this cannot just be judged by scientists alone. Indigenous people’s culture and sustainability circumstances have long been the subject of academic research, the outcomes of which are often not particularly useful to local Indigenous communities (Tobias et al. 2013; Chilsa 2019). There are increasing calls for Indigenous-driven research that identifies the knowledge priorities of Indigenous communities, and for Indigenous-research partnerships to generate knowledge that Indigenous people can use to make informed sustainable decisions (Harfield et al. 2020; Zurba et al. 2019). The devolution of control over conservation decisions and resources to local and Indigenous communities has increased the need and demand for assessments of ‘conservation success’ to be broadened to include local assessments (Corrigan et al. 2018).

Attention to this indicator to inform adaptive learning and management of this project has provided insights into how Indigenous-led evaluation of research can be done. Insights from the evaluation process opened up critical analysis but we worked together to focus on identifying what works, which created opportunities for ongoing learning and sustainability. The strengths-based approach used is particularly valuable for evaluating research projects, as most funding involves short timeframes and discrete activities. Evaluation of research in such contexts can enable Indigenous collaborators to consider what should and can be done in a project’s timeframe and drive the legacy impacts and benefits for Indigenous people once researchers have left.



Figure 11. Tracking science and Bininj/Munggyu knowledge sharing, and co-research activities supported by Kakadu National Environmental Science Program (NESP) project.

4. *Bininj/Mungguy* indicators as decision triggers for adaptive joint management

This project has co-developed *Bininj/Mungguy* indicators and shown how and why these indicators can be used to guide adaptive joint-management decision-making in Kakadu National Park. *Bininj/Mungguy* indicators that were selected by the *Bininj/Mungguy* Research Steering Committee focused on Country and bush tucker; culture and community; economic and training benefits; and the practices and benefits of knowledge sharing between Indigenous people, and between Indigenous and science collaborators. Together, these *Bininj/Mungguy* indicators reflect the holistic aspects of Indigenous assessments of Country and its health, which include a regard for the role and responsibilities underpinning human–human and human–non-human interactions and care.

We trialled the application of these *Bininj/Mungguy* indicators to guide adaptive joint decision-making and on-ground management at two sites that represent significant landscapes in Kakadu National Park. The Nardab floodplain is an Indigenous bio-cultural landscape, a Ramsar-listed site of environmental significance and is near a popular tourist destination. *Bininj/Mungguy* indicators were used to adaptively tackle the spread of para grass weed at priority wetland sites across the floodplain. At Jarrangbarnmi, we focused on the complex issues of landscape burning care for a woodland for which Traditional Owners have responsibility for and which is next to a popular and remote tourist camping area.

Innovative approaches to monitor these *Bininj/Mungguy* indicators have been developed and used to support on-ground *Bininj/Mungguy* assessments of each priority area. We made a concerted effort to draw on all the selected indicators to assess the health of each site rather than just focusing on any one particular (e.g. Country) indicator. The development of Indigenous protocols and approaches to use digital technology and artificial intelligence provided us with another viewpoint and source of analysis to assess the changing health of Country before and after agreed activities.

A dashboard was co-designed as part of this project and enables Traditional Owners, scientists and park managers to draw on the multiple sources of Indigenous, scientific and management evidence and have a dialogue around what the data collected to monitor these *Bininj/Mungguy* indicators means in terms of triggering the next decision or action. This adds to existing research that has developed Indigenous indicators and monitoring and evaluation frameworks, but do not yet show how indicators might explicitly trigger management or policy decisions (Caillon et al. 2017; Sterling et al. 2017). The lack of practical research on using indicators to trigger management decisions is surprising given the importance of Indigenous lands for biodiversity conservation, the growing and global recognition of Indigenous rights to and relationships with the environment, and the role that culture plays in enhancing the beneficial contributions between nature and people (Diaz et al. 2018; Garnett et al. 2018).

Together, we have started to fill this gap by identifying how Indigenous indicators and decision triggers developed by *Bininj/Mungguy* were defined locally, negotiated regionally and used to inform adaptive co-management decisions in this World Heritage area. The work challenges conventional approaches to using decision triggers for conservation management which rely only on an ecological attribute to understand the state of the system. The boundary or ‘threshold of potential concern’ between the zones of desirable and

undesirable ecosystem states becomes the trigger for action, informed by monitoring the ecological attribute (Addison et al. 2015; Bestelmeyer 2006; Biggs and Rogers 2003). We extended this concept by asking *Bininj/Mungguy* to take a 5-point evaluation to describe their knowledge of the state of Country at selected sites and then used this assessment to explicitly inform actions that Kakadu co-managers could support to restore system attributes of each area.

Importantly, when *Bininj/Mungguy* assessed indicators as 'healthy' (a rating of 4 to 5), this triggered a decision as often as those assessments that evaluated indicators as being in an unhealthy state. For example, at Nardab, Country and knowledge sharing indicators were assessed as healthy after para grass control efforts, but this assessment still triggered a decision to continue working on knowledge-sharing efforts as this was viewed as critical to maintain the health of this wetland. Often, decisions recommended after site assessments triggered small experimental actions, like visiting Country again together, or doing a small early dry season, on-ground burn before it rained, or inviting young people to participate as co-researchers on the team by interviewing Elders doing assessments of Country. Together, we could explicitly link Indigenous indicators to actions or decisions and use this to negotiate where, what and why resources or management interventions needed to be prioritised or shifted. We hope to extend this work in the future by considering how decision triggers for action could be incorporated into joint management monitoring and evaluation frameworks and into our Healthy Country AI dashboard.

References

- Addison, PFE, De Bie, K and Rumpff, L (2015) 'Setting conservation management thresholds using a novel participatory modeling approach', *Conservation Biology*, 29(5):1411-1422.
- Austin, BJ, Vigilante, T, Cowell, S. et al. (2017) 'The *uunguu* monitoring and evaluation committee: Intercultural governance of a land and sea management programme in the Kimberley, Australia', *Ecological Management & Restoration*, 18(2):124-133.
- Austin, BJ, Robinson, CJ, Mathews, D. et al. (2019) 'An Indigenous-Led Approach for Regional Knowledge Partnerships in the Kimberley Region of Australia', *Human Ecology*, 47:577-588.
- Bestelmeyer, BT (2006) 'Threshold concepts and their use in rangeland management and restoration: the good, the bad, and the insidious', *Restoration Ecology*, 14:325-329.
- Biggs, HC, and Rogers, KH (2003) 'An adaptive system to link science, monitoring and management in practice', *The Kruger experience: Ecology and management of savanna heterogeneity*, 59-80.
- Caillon, S, Cullman, G, Verschuuren, B and Sterling, EJ (2017) 'Moving beyond the human-nature dichotomy through biocultural approaches', *Ecology and Society*, 22(4).
- Cámara-Leret, R, and Dennehy, Z. (2019) 'Information gaps in indigenous and local knowledge for science-policy assessments', *Nature Sustainability*, 2(8):736-741.
- Chilsa, B (2019) *Indigenous research methodologies*, Sage Publications.
- Corrigan, C, Robinson, CJ, Burgess, ND, Kingston, N, and Hockings, M (2018) 'Global review of social indicators used in protected area management evaluation', *Conservation Letters*, 11:1-9.
- Díaz, S, Pascual, U, Stenseke, M et al. (2018) 'Assessing nature's contributions to people', *Science*, 359(6373):270-272.
- Garnett, ST, Burgess, ND, Fa, JE et al. (2018) 'A spatial overview of the global importance of Indigenous lands for conservation', *Nature Sustainability*, 1:369-374.
- Harfield, S, Pearson, O, Morey, K et al. (2020) 'Assessing the quality of health research from an Indigenous perspective: the Aboriginal and Torres Strait Islander quality appraisal tool', *BMC medical research methodology*, 20, 1-9, doi:10.1186/s12874-020-00959-3.
- Hockings, M, Stolton, S and Dudley, N (2006) *Evaluating effectiveness: A framework for assessing the management of protected areas*, IUCN (International Union for Conservation of Nature and Natural Resources), Gland, Switzerland/Cambridge, UK.
- McKemey, M, Ens, E, Rangers, YM, Costello, O and Reid, N (2020) 'Indigenous knowledge and seasonal calendar inform adaptive savanna burning in northern Australia', *Sustainability*, 12(3):995.
- Robinson, CJ and Wallington, TJ (2012) 'Boundary work: engaging knowledge systems in co-management of feral animals on Indigenous lands', *Ecology and Society*, 17:16.

Robinson, CJ, Maclean, K, Hill, R, Bock, E, and Rist, P (2016). Participatory mapping to negotiate Indigenous knowledge used to assess environmental risk', *Sustainability Science*, 11(1):115–126. doi:10.1007/s11625-015-0292-x.

Sterling, EJ, Betley, E, Sigouin, A et al. (2017) 'Assessing the evidence for stakeholder engagement in biodiversity conservation', *Biological Conservation*, 209:159-171.

Tobias, JK, Richmond, CAM, and Luginaah, I (2013) 'Community-based participatory research (CBPR) with Indigenous communities: Producing respectful and reciprocal research', *Journal of Empirical Research on Human Research Ethics*, 8:129-140.

Zurba, M, Maclean, K, Woodward, E, and Islam, D (2019) Amplifying Indigenous community participation in place-based research through boundary work', *Progress in Human Geography*, 43(6):1020-1043.

Appendix 1: Summary of media, community newsletters and academic outputs

For Healthy Country AI collaboration

Substantial traditional media coverage across Australia, amounting to a reach of over seven million. This included:

- Government News: Managing Kakadu with AI and Indigenous intelligence (<https://www.governmentnews.com.au/managing-kakadu-with-ai-and-indigenous-intelligence/>)
- Business Insider Australia: Microsoft teamed up with Indigenous traditional owners in Kakadu, using AI and drones to rehabilitate parts of the national park (syndicated to Yahoo! News; <https://www.businessinsider.com.au/microsoft-indigenous-ai-kakadu-2019-11>)
- Business Insider Australia: 10 things you need to know this morning in Australia (syndicated to Yahoo! News; <https://au.finance.yahoo.com/news/10-things-know-morning-australia-221106856.html>)
- The Canberra Times: Share the good news – Letters to the editor (<https://www.canberratimes.com.au/story/6506914/share-the-good-news/>)
- National Indigenous Times: AI and Traditional Knowledge combine to rehabilitate Kakadu National Park (<https://nit.com.au/ai-and-traditional-knowledge-combine-to-rehabilitate-kakadu-national-park/>)
- The Fifth Estate: Fusing AI, science and Indigenous knowledge to tackle Kakadu's weed woes (<https://thefifthestate.com.au/urbanism/environment/fusing-ai-science-and-indigenous-knowledge-to-tackle-kakadus-weed-woes/>)
- The Courier Mail: Eco-AI help for Kakadu (in print, not available online)
- The National Tribune: AI transforms Kakadu management (<https://www.nationaltribune.com.au/ai-transforms-kakadu-management/>)
- 7News: Microsoft teams up with Kakadu's owners (syndicated to Yahoo! News, Canberra Times, The Daily Mail and The West Australian + 120 more; <https://7news.com.au/weather/environment/microsoft-teams-up-with-kakadus-owners-c-567926>)
- The Australian: Microsoft teams up with Kakadu's owners (syndicated to Daily Telegraph, Herald Sun + over 10 more; <https://www.dailytelegraph.com.au/news/national/microsoft-teams-up-with-kakadus-owners/video/e82bf1e8f6b2fcff9169d8ba73e452ff>)
- NT News: Bird's-eye view aids in key Kakadu fight (in print, not available online)
- ZDNet: Drones and AI making a dent in Kakadu's war against weeds (<https://www.zdnet.com/article/drones-and-ai-making-a-dent-in-kakadus-war-against-weeds/>)
- Computerworld, CSIRO: Microsoft project combines AI with Indigenous knowledge to protect national parks (<https://www.computerworld.com/article/3488138/csiro-microsoft-project-combines-ai-with-indigenous-knowledge-to-protect-national-parks.html>)
- iTWire: Microsoft, CSIRO partner with Kakadu National Park on environmental project (<https://www.itwire.com/strategy/microsoft,-csiro-partner-with-kakadu-national-park-on-environmental-project.html>)

Communications supported through our CSIRO channels

- CSIROscope blog: 437 unique pageviews, 4:43 seconds spent on page (this is much higher than the average 2:57 seconds)
- Tweet 1: 7,540 impressions, 156 engagements
(<https://twitter.com/CSIRO/status/1196947461081690112>)
- Tweet 2: 5,458 impressions, 65 engagements
(<https://twitter.com/CSIRO/status/1197031820681981952>)
- Tweet 3: 4,421 impressions, 26 engagements
(<https://twitter.com/CSIRO/status/1197348911448330240>)
- Tweet 4 with video: 8,507 impressions, 2,306 people watched the film, 293 engagements
(<https://twitter.com/CSIRO/status/1198058585491726337>)
- Facebook 1: 19,048 reached, 502 engagements
(<https://www.facebook.com/CSIROnews/posts/10157056753928843>)
- Facebook 2 with video: 21,225 reach, 881 engagements. 'Great to see ancient wisdom and knowledge connecting with modern technology'.
(<https://www.facebook.com/watch/?v=2275600989405255>)

Finally, the blog has been repurposed for an article in CSIRO's Double Helix in 2019.

2019 Eureka Prize finalist

Six media and newspaper articles and three significant social media posts generated total audience reach of 648,375.

- SBS News: Indigenous scientists in the running for the 'Oscars' of Australian science
(<https://www.sbs.com.au/nitv/article/2020/10/01/indigenous-scientists-running-oscar-australian-science>)
- Koori Mail: Kakadu project is Eureka finalist (in print, not available online)
- The NT News: Eco-project up for gong (in print, not available online)
- CSIRO Newsroom: Indigenous science celebrated in CSIRO finalists for Eureka Prizes
(<https://www.csiro.au/en/News/News-releases/2020/Indigenous-science-celebrated-in-CSIRO-finalists-for-Eureka-Prizes>)
- UWA News: Indigenous-led science to co-manage Kakadu named Eureka finalist
(<https://www.uwa.edu.au/news/article/2020/september/indigenous-led-science-to-co-manage-kakadu-named-eureka-finalist>)
- CDU News: CDU researchers take places as Eureka finalists
(<https://www.cdu.edu.au/news/cdu-researchers-take-places-eureka-finalists>)
- AM Eureka Prizes Twitter post 1
(<https://twitter.com/eurekaprizes/status/1310756178096353280>)
- AM Eureka Prizes Twitter post 2
(<https://twitter.com/eurekaprizes/status/1330632901554298883>)
- AM Eureka Prizes Twitter post 3
(<https://twitter.com/eurekaprizes/status/1310768756499464192>)

Appendix 2: Using knowledge to care for country: Indigenous-led evaluations of research to adaptively co- manage Kakadu National Park, Australia

Robinson, C.J., Macdonald, J.M., Douglas, M., Perry, J., Setterfield, S., Cooper, D., Lee, M., Nadji, J., Nadji, S., Nayinggul, A., Nayinggul, A., Mangiru, K., Hunter, F., Coleman, B., Barrowei, R., Markham, J., Alderson, J., Moyle, F., May, K., N. Bangalang 2021. Using knowledge to care for country: Indigenous-led evaluations of research to adaptively co-manage Kakadu National Park, Australia. *Sustainability Science*.
<https://doi.org/10.1007/s11625-021-01015-9>

Abstract

Sustainability science research conducted with Indigenous collaborators must be Indigenous-led and achieve impacts that are grounded in local values and priorities, both for ethical reasons and to achieve more robust outcomes. However, there has been limited focus on determining how best to evaluate the way research is used, shared, and created to adaptively solve complex sustainable issues facing Indigenous lands. In this paper, we outline an approach for conducting Indigenous-led evaluations of sustainability research and show how this approach was applied to evaluate cross-cultural knowledge co-production practice and impact in Australia's jointly managed Kakadu National Park. As part of an Indigenous-led research project, indicators were developed by Indigenous project partners to monitor the health of the knowledge-sharing and co-production practices that underpinned the design, management, and success of the project's research activities. The evaluations focused on determining whether research activities were providing the negotiated benefits for local Indigenous people; helped restore and protect agreed values in priority areas within this joint managed World Heritage Area; and supported Indigenous-led collaborative knowledge sharing and research practices. The approach shows how sustainability science can be evaluated by Indigenous leaders to test if and how research responds to Indigenous priorities for their traditional estates. In Kakadu, we show how Indigenous-led design and evaluation of research empowered the usability and benefits of knowledge collaboratively negotiated, shared and co-created so that knowledge practice and impact responded to local Indigenous priorities facing the sustainable management of their livelihoods and estates.



Negotiating where and what research activities were required to adaptively monitor the health of landscapes at Jarrangbarimi. Credit: Michael Douglas.

Appendix 3: Understanding Indigenous values to prioritise on ground conservation efforts: lessons from the Nardab floodplain in Kakadu National Park

Na-gangila Bangalang¹, Johnathan Nadji¹, Anita Nayinggul¹, Sean Nadji^{1,2}, Alfred Nayinggul¹, Simon Dempsey^{1,2}, Kenneth Mangiru¹, James Dempsey^{1,3}, Serena McCartney^{1,2}, Jennifer Mairi Macdonald^{4,5} and Cathy J Robinson^{5*}

Submitted to: Journal of Ecological Management & Restoration (Special Indigenous Edition)

Abstract

The Nardab floodplain in northern Australia is an international Ramsar-listed site that has always been an important cultural landscape owned by *Bininj* (local Indigenous) Traditional Owners. *Bininj* visit the floodplain to care for *djang* (sacred sites) and to hunt, including for *ngalmangeyi*, *kedjebe*, *manimunak*, and *djenj* (long-necked turtle, file snakes, magpie geese, and fish) which are shared with kin and local families. *Bininj* have shared their floodplain with non-Indigenous people for hundreds of years, including through arrangements established under the World Heritage listed Kakadu National Park. Today, the floodplain is being overrun by para grass, a weed threatening multiple *Bininj* and conservation values. Due to the scale of para grass infestation, *Bininj* and joint managers needed to choose priority areas for on-ground management attention. We draw on our *Bininj*-led collaborative work at Nardab to explore the specific combinations of *Bininj* values at selected locations on the Nardab floodplain, which included the capacity of the site to support suitable habitat for significant bush tucker species; knowledge sharing activities; and/or the ecosystem services enjoyed by visiting tourists. These specific combinations of *Bininj* values informed decisions on where and what actions were prioritised for weed management and Indigenous stewardship activities. The diversity of meaning and metrics around *Bininj* values on the Nardab floodplain echo the complexity of Indigenous values for country across Australia and need careful discussion and understanding to enable Indigenous-led environmental management and restoration priorities and activities.

Appendix 4: Using Indigenous-designed artificial intelligence to support Indigenous-led adaptive management

Journal paper (In prep)

Robinson, C.J., Perry, J., Macdonald J.M., van Bodegraven, S., Setterfield, S., Nadji, J., Bangalang, N., Nayinggul, A., Nadji, S., Dempsey, S., McCartney, S., Taylor, A., Hunter, F., May, K., Moyle, F., Cooper, D., Gilfedder, M., Douglas, M.

Abstract

Most of the planet's vital ecosystems are managed on lands owned by Indigenous peoples. Indigenous people face many challenges in managing these lands, including rapidly growing threats causing species extinctions and ecosystem losses. In response, many Indigenous groups are looking for ethical ways to design and apply innovative technologies to solve complex environmental management problems—specifically, technology that can work with Indigenous knowledge (IK). Here, we explain the features of Indigenous-led Artificial intelligence (I-AI) and show how it enabled Indigenous people in Australia's Kakadu National Park, a World Heritage Area listed for its natural and cultural values, to use their local knowledge to design and apply artificial intelligence (AI) for optimised adaptive learning and improved decision-making. While the learning inputs and logics of IK and AI are vastly different, our analysis of I-AI trained models show how IK/AI learning can work together to empower Indigenous people and co-management partners achieve environmental management goals.

Appendix 5: Indigenous-led responsible innovation: lessons from co-developed protocols to guide the use of drones to monitor a biocultural landscape in Kakadu National Park, Australia

Macdonald, JM., CJ Robinson, J Perry, M Lee, R Barrowei, B Coleman, H Ford, J Douglas, J Hunter, A Barrowei, J Markham, B Markham, E Gayoso, T Ahwon, D Cooper, S Setterfield, M Douglas, in press. *Journal of Responsible Innovation*

Abstract

The scholarship and practice of responsibly navigating the disruptive possibilities of new technologies has yet to fully consider Indigenous worldviews. Here we draw on Indigenous-led research in northern Australia's Kakadu National Park to reflect on research practices for navigating the introduction of aerial drones as a tool for local Indigenous co-managers to monitor and manage this World Heritage Area. We co-developed protocols to guide Indigenous-led innovation – empowering Indigenous governance, developing ethical and trusted research relationships, and enabling ongoing Indigenous-led technological innovation. We applied the protocols to negotiate and navigate the use of drone technology at Jarrangbarnmi, an important biocultural landscape in country owned by Jawoyn people in northern Australia. These protocols provide a way for Indigenous cultural responsibilities for knowledge sharing and stewardship of country to guide and authorise the co-design and application of technological innovations, which are increasingly being used to produce new knowledge to adaptively co-manage Indigenous people's lands and seas.

